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Re-evaluating Primary Biotic Resource Use for Aquatic Biomass Production: A New Calculation Framework

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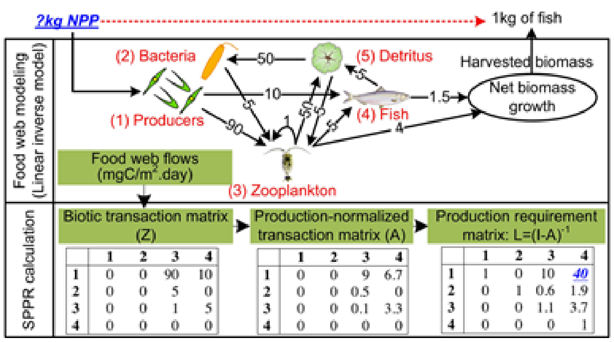
Introduction

Biotic resource used for biomass production can be quantified through the specific primary production required (SPPR), which is the amount of net primary production needed to produce one unit of (harvested) biomass. As such, SPPR has been used to quantify the impacts of biomass harvesting in environmental impact assessments[1] and ecological studies[2]. Existing approaches calculation of SPPR based on food chain theory or by simplifying food web structure by removing energy/material cycles, leading to distortions of SPPR estimates. Therefore, we constructed a new calculation framework that explicitly takes into account full food web complexity when estimating SPPRs.

Material and method

Our new approach calculated SPPR from a food web flow matrix, which expressed the transfer of mass/energy within the ecosystem and between the ecosystem and its surrounding environment. Three core matrices in our new calculation framework were derived to calculate SPPR: (1) the biotic transaction matrix ($Z=[z_{ij}]_{nxn}$) was constructed by considering all transfer from the i^{th} to the j^{th} living species (z_{ij}) adjusted for indirect transfer of energy/material from producers to higher trophic levels through detrital materials; (2) the production-normalised transaction matrix ($A=[z_{ij}/p_j]_{nxn}$) was then calculated by normalizing the elements of each column of Z by the production of the living compartment corresponding to that column (p_j); (3) the production requirement matrix was calculated as $L=(I-A)^{-1}$, where I is the identity matrix. Each element l_{ij} represented the amount of material from the i^{th} living species that was directly and indirectly required to produce one unit of the j^{th} species's production. SPPR of the j^{th} living species was the element corresponding to the primary producers in the j^{th} column of L (Fig. 1).



Biotic transaction matrix (Z)

	1	2	3	4
1	0	0	90	10
2	0	0	5	0
3	0	0	1	5
4	0	0	0	0

Production-normalized transaction matrix (A)

	1	2	3	4
1	0	0	9	6.7
2	0	0	0.5	0
3	0	0	0.1	3.3
4	0	0	0	0

Production requirement matrix: $L=(I-A)^{-1}$

	1	2	3	4
1	1	0	10	40
2	0	1	0.6	1.9
3	0	0	1.1	3.7
4	0	0	0	1

Fig. 1 New calculation framework for calculation of SPPR which can be coupled to food web modelling technique[3].

We compared the results of our approach with the simplification approach (excluding cycling) for two cases on the Icelandic marine ecosystem (low cycling) and the northern Gulf of St. Lawrence ecosystem (high cycling) to investigate the influence of food web simplification on SPPR estimates.

Results and Discussion

The ratio $SPPR_{complex}$ (our new approach)/$SPPR_{simple}$ (approach with a simplified food web structure) was highly species-specific, ranging between 1 (molluscs) to 2.3 for red fish in the Northern Gulf of St. Lawrence and from 1 (e.g., herring, capelin) to 2.8 (toothed whales) for the Icelandic marine ecosystem. For adult cod (*Gadus morhua*), the species harvested most intensely in both ecosystems (> 45% of total catches), this ratio was 1.7 (the northern Gulf of St. Lawrence) and 1.1 (the Icelandic marine ecosystem). These differences illustrated that food web complexity can greatly influence SPPR estimates and that removing cycles can lead to underestimation of SPPR. This underestimation of SPPR estimates led to lower impacts of biomass exploitation and smaller ecological footprint of marine-based ingredient of a product. For example, ecological footprint of adult cod will be 1.7 and 1.1 times lower for two above ecosystems, respectively. The influence of removing cycles on SPPR estimates was more pronounced for the ecosystem with higher degree of cycling (the northern Gulf of St. Lawrence). Besides, our new framework can also be coupled to food web modelling (e.g. linear inverse model) to examine how uncertainty on ecological data and processes can be accounted for while estimating SPPR[3].

Conclusion

Our new calculation framework offered advantages to existing approach for calculating SPPRs by considering the full food web complexity. Improvements on SPPR estimates will then contribute to better quantification of biotic resource use in life cycle assessment and ecological footprint analysis for aquatic biomass production.

Acknowledgments

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